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# 7.62-mm PRIMER/PROPELLANT INTERFACE STUDY

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An engineering study was conducted on the 7.62-mm ball cartridge, M80, to determine the cause of a recurring delayed propellant ignition and to identify possible causes of action to correct the problem.

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## INTRODUCTION

An investigation was conducted in 1993 by the Small Caliber Ammunition branch to address problems being encountered by the Lake City Army Ammunition Plant (LCAAP) in meeting the specification for tetracene used in the manufacture of small caliber primers. As part of this investigation, pressure-time curves were recorded for 7.62-mm ammunition using M34 primers containing various batches of tetracene. Examination of these curves brought to light an unusual phenomenon in the standard 7.62-mm M80 ball ammunition (fig. 1). While the M62 tracer ammunition exhibited pressure-time curves that were essentially classical in shape, M80 ball ammunition consistently produced curves with substantial ignition delays on the order of 0.3 to 0.4 ms (fig. 2). This occurs even though both cartridges use the same primer and a comparable weight of the same propellant.

Further examination of acceptance test records for this ammunition over the previous 6 yrs revealed widely variable action time measurements as well as a significant number of hangfires in function and causality firings. Both of these conditions are commonly related to ignition deficiencies such as the delay just discussed.

Based on this, it was considered essential in the interest of continued production of quality ammunition that the interface between the primer and the propellant in these cartridges be assessed for adequacy and corrective action implemented where required.

The 7.62-mm M80 ball ammunition is used in both gas operated and motor driven ammunition feed applications. Weapons that operate with a gas feed system operate by using the propellant gas pressure as the projectile passes the gas port in the weapon. In the case of the M80 ball round, an ignition delay was occurring with the propellant that unless being tested/timed would only be noticed in a gas operated weapon as a temporary reduction in the rate of fire. However, this would not stop the weapon from operating correctly. Conversely, with a motor driven weapon, there is a specific time window based on the speed of the driving motor that determines the minimum acceptable action time (time between primer indent and muzzle exit) in which the projectile must exit the breech so that damage to the weapon or injury to the operator does not occur.

The 7.62-mm M80 ball round has repeatedly been restricted to use in weapons that are gas operated. However, the M134 minigun is a motor driven automatic machine gun that is driven at a predetermined feed rate. Due to this concern, this engineering study was initiated by the U.S. Army Armament Research, Development and Engineering Center (ARDEC) when it was discovered that the pressure-time traces for the M80 displayed the characteristics of improper propellant ignition that resulted in delays between primer indent and bullet exit.

## OBJECTIVE

The objective of this engineering study was to identify and correct the cause of the delayed ignition of the propellant in the 7.62-mm M80 ball cartridge (fig. 2). This delay can be seen as a step in the pressure-time curve. Identification of the cause and implementation of a solution is expected to yield an improvement in the reliability of 7.62-mm M80 ammunition. Associated benefits of this are a reduction in waivers and the accompanying use restrictions on ammunition lots due to failure of function and casualty testing, and the elimination of hangfires associated with the 7.62-mm M80 ball round.

## APPROACH

There are many variables that can have an effect on the performance of the M80 ball ammunition. For this study, the factors chosen were the primer, the free-space volume inside the case, and the bullet types: ball and tracer. These were chosen for the reasons outlined next.

At the time of this study, it was known that the manufacturing process for primers at the LCAAP did not produce primers that had consistent performance. This led to the investigation into the effect of the primer on the propellant performance. The free-space volume and bullet type were included because the M62 tracer round is assembled in the same case as the M80 as well as using the same propellant, but does not have the ignition delay problems that the M80 has. The differences here centered on how far the bullet protruded into the case (free-space volume), and whether the tracer was adding any impetus to the propellant burning rate (bullet type).

Prior to conducting the factorial test, a pretest was done that assessed whether crimping the case around the bullet would have any affect on this test. This was conducted to assess the difference between crimped and non-crimped rounds with respect to performance. This was used to assess whether crimping would be a factor in the factorial testing, which could lead to inconsistent results. It was decided that upon completion of this test, the decision would be made whether or not to crimp each round used in the factorial test.

The procedure used for the factorial study established the following performance parameters in terms of the time-to-peak pressure, peak pressure, and velocity:

- The baseline performance of the M80 ball round and the M62 tracer

- The performance related to a change in primer only, using the M43 primer in place of the M34

- The performance related to a change in free-space volume by altering bullet depth

- The performance related to a change in both free-space volume and primer at the same time.

This resulted in an eight element table of tests to be performed (table 1) on the 7.62-mm round. For the previously mentioned rounds, time-to-peak pressure, peak pressure, and velocity were recorded during all tests.

After completion of the pretest, the factorial test was then initiated. A sample of 27 rounds for each trial was deemed to be a statistically significant sample.

Thirty rounds were assembled for each trial, which was done by assembling combinations of the 120 M80 rounds, 120 M62 rounds, and 120 M118 rounds obtained. From these rounds, the following components were used: All three cartridges use the same case, thus they were interchangeable. The M118 round uses an M43 primer as compared to the M34 primer used in the M62 and M80 rounds. Propellant for each round always followed the bullet that it was originally assembled with.

As shown previously in table 1, there are eight separate combinations that were tested. The first two variables investigated (for trial 1 and 2) were the intrusion depths. The intrusion depth is the measurement of the bullet intrusion into the case. The M80 cartridge has a bullet intrusion of 0.40 in. The M62 cartridge has a bullet intrusion of 0.57 in. Since the M62 does not suffer from the same propellant ignition delay problems as the M80, this was one of the variables investigated. The deeper intrusion depth of the M80 bullet into the case was achieved by pressing the M80 bullet deeper into the case for a total overall length of 2.63 ± 0.03 in.

Trial 3 and 4 investigated the effect that will occur due to a change in primer. The standard primer was replaced with one that is more robust to determine the propellant ignition characteristics. These trials used the case and M43 primer from the M118 round and altered intrusion depths to see if there was an effect due to the M43 primer. This test also used the M80 bullet and the propellant from the M80 cartridge.

The next four tests all used the M62 tracer bullet. This was run to see if the tracer was adding any impetus to the propellant burn rate. First, in trial 5, the intrusion was reduced to equal that of the M80 cartridge, 0.40 in. Trial 6 tests the standard M62 round.

Again, in order to quantify any differences that the primer may have on the propellant burn rate, the primer type was changed for the tracer round as was done for the ball round. The tracer round was inserted into the M118 case at two depths, 0.40- and 0.57-in. intrusions. The propellant from the tracer cartridge was also used in the M118 case.

After the factorial testing was complete, a follow-on test was initiated to ensure that the propellant differences between the M62 and the M80 were not a factor. There is a difference in the percent of calcium carbonate used in the propellant (both use WC-846 propellant). This test fired baseline rounds of both the M80 and the M62 cartridges, as well as cartridges in which only the bullets were switched. Additionally, there were also a series of nose tap and base tap tests done on M80 rounds to ensure that any differences being seen were not due to propellant position. Intrusion depth was set at standard depth for the bullet under test. The test matrix was as follows:

| Configuration | No. of rounds |
|---|---|
| Standard M80 ball | 15 rounds fired |
| M80 projectiles with M62 case and propellant | 15 rounds fired |
| Standard M62 tracer | 15 rounds fired |
| M62 projectiles with M80 case and propellant | 15 rounds fired |
| Standard M80 ball, nose tap | 15 rounds fired |
| Standard M80 ball, base tap | 15 rounds fired |

After completion of the factorial testing, an analysis was done on the results to assess the cause of the slow propellant ignition and subsequent delayed time to peak pressures. From this, a plan of action was put together in order to pursue a task order contract in which a limited amount of ammunition would be produced using the "improved" configuration. If it was found that the improved ammunition produced the expected results, an appropriate number of rounds would be produced to conduct qualification testing at U.S. Army Test and Evaluation Command (TECOM), Aberdeen Proving Ground, Maryland.

Based on the results of this testing, a three part task order contract was written for LCAAP.

## LAKE CITY ARMY AMMUNITION PLANT TESTING

### Phase I Testing

The objective of the phase I testing of the LCAAP task order contract was to further narrow and identify the factor that would eliminate or most nearly eliminate the delayed ignition problem in the M80 ball round.

The contractor was tasked to perform ballistic testing as outlined.

Each configuration was fired in three series of 30 rounds. All rounds were fired at -65°F. The following data points were taken from each round:

- Mid-case pressure and action time tests were conducted and pressure-time traces were taken. Dual trace printouts were provided in hard copy formats for mid-case and case mouth pressure testing. Trace start began at time zero, defined as primer indent. Hard copy prints of the associated curves were provided to show the time trace from primer indent to peak pressure, emphasizing the time between primer indent and 15,000 psi.

- Port pressure measurements were made concurrently with the action time testing during phase I. Values were recorded for each round.

- Muzzle velocity was taken for each round tested. Two velocity screens were set up, one at 28 ft and the second at 128 ft for a 78-ft velocity measurement.

The following test procedures were followed:

- Mid-case pressure. Cases were drilled 0.75 in. from the head of the case for mid-case pressure tests prior to conditioning. Cartridges were fired one shot at a time for chamber pressure measurements in a universal receiver using a rigid mount. The electric pressure, velocity, and action time test barrel was secured to a rigid mount. A 180 KHz electronic filter was applied. These rounds were fired at a rate less than one round per minute as described in paragraph 2, section 7-13 of the TECP 700-700, Vol. III.

- Action time. The action time test was conducted in accordance with SCATP-7.62, <u>Test Procedures for 7.62-mm Cartridges</u>, section 4. Firing was done one shot at a time, no faster than one round per minute, for action time measurements in a Universal receiver using a test barrel secured to a rigid mount.

- Port pressure. The port pressure test was conducted in accordance with SCATP-7.62, <u>Test Procedures for 7.62-mm Cartridges</u>.

- Velocity. Cartridges were fired one shot at a time for velocity measurements in a universal receiver using a rigid mount. The test barrel was secured to a rigid mount. The test was conducted in accordance with SCATP-7.62.

- Conditioning. Phase I testing was done at a single temperature. The cartridges were conditioned at –65° ± 2°F for not less than 6 hrs.

**Phase II Testing**

Phase II testing required that more in depth testing of the most promising cartridge configuration be conducted. This testing was conducted with cartridges that were fabricated on an assembly line, as opposed to fabrication by hand, which was done in phase I. This phase was done as follows:

- The contractor (LCAAP) fabricated all the necessary tooling and performed the required set-up in order to manufacture 900 cartridges of the final selected configuration. The contractor assembled the cartridges of the chosen configuration to an overall length of 2.80 to 0.03 in. as called out in the M80 drawing (10521998). The cartridge components were the same as those employed in the standard M80 ball round, excluding the chosen factor. The factor changed was determined from phase I.

The contractor ensured that all the cartridges were waterproofed as shown in drawings 10521998 and 10523088. The contractor also performed ballistic testing as outlined next.

- Mid-case pressure, case mouth pressure, velocity, and action time tests were conducted concurrently and pressure time traces were taken. The 900 rounds were fired at each of three temperatures (-65°F, 70°F, and 155°F). All tests were conducted in groups of 30 rounds. Dual trace were provided for mid-case and case mouth pressure testing. Trace start began at time zero (primer indent). Hard copy prints of the associated curves were provided that showed complete time trace-to-peak pressure and emphasize the time between primer indent and 15,000 psi.

- Muzzle velocity was taken for each round fired. Two velocity screens were set up, one at 28 ft and the second at 128 ft for a 78-ft velocity measurement.

- All tests were conducted at cold, ambient, and hot temperatures as outlined in TECP 100-100, Vol. III, section 7-24.

**Phase III Assembly**

Upon completion of Part II testing, ARDEC was to review the test results. Based upon analysis done by ARDEC on the data provided by the LCAAP, the decision to proceed would be made. If the decision to proceed were made, the contractor would then fabricate 140,000 phase II cartridges for qualification testing at Aberdeen Test Center (ATC). The contractor would then deliver all cartridges to the ATC for independent government test and evaluation.

## TESTING AND RESULTS

### Pretest

Initial testing centered on preparations for the factorial test. Since this study centered on the lack of consistency of the M80 round, it was crucial to minimize the introduction of additional inconsistencies during the testing of the factorial test. However, due to the added manpower necessary to crimp the cartridge cases around the bullets, it was decided to conduct a small test prior to the factorial test to assess whether crimping of the cases was a necessary step. The testing centered on velocity and case mouth pressures. It was presumed that if this test yielded consistent results between the crimped and the non-crimped rounds, crimping was an unnecessary step.

This test used M80 ammunition only: reference M80; M80 cartridges that had the bullets pulled, replaced, then crimped; and M80 cartridges that had the bullets pulled and replaced with no crimp. The reference rounds were fired at ambient temperature only. The test rounds fired at ambient, hot (125°F), and cold (-65°F) temperatures. As can be seen from table 2, the differences between the non-crimped and the crimped rounds were obvious. By not crimping the case around the bullet, the differences in the standard deviations of the velocity at ambient temperature was greater than 500 ft/s, which is over 20% of the total velocity measurement. The differences between the pressure standard deviations were also large, with the non-crimped rounds showing a standard deviation of nearly five times greater than that of the crimped rounds. At the hot and cold temperatures, differences were again seen, but not as drastic as at ambient. Again, the differences here were greater for the non-crimped rounds than the crimped rounds. It was thus decided that the rounds used in the factorial test must be crimped in order to achieve good results.

### Factorial Test

The factorial test was then initiated. This factorial test was designed to discriminate between the effects of the factors on time-to-peak pressure, where a minimum time was being pursued. As was previously shown in table 1, the factorial test had eight configurations that included all three of the variables being investigated.

Since the object of this test was to minimize the time to peak pressure, it was decided that statistically, a single tailed test was appropriate where the object of concern was only the maximum time. In order to ensure a 0.90 probability of detecting effects as small as 0.01, it was found, based on historical data from LCAAP, that a minimum of 27 round per trial were necessary.

Since the greatest effects in the pretest were found to occur at ambient temperatures and there was no historical data that disputed this, all the factorial testing was performed at ambient temperatures.

The ammunition used for this test were M80 ball rounds, M62 tracer rounds, and the cases and primers from M118 match rounds. The ammunition came from the following lots:

| Cartridge | Ammunition type | Lot number |
|---|---|---|
| M80 | Ball | LC-92K106-083 |
| M62 | Tracer | LC-93B112-759 |
| M118 | Special ball | ------------ |

The ammunition for this test was assembled at the ARDEC test range. Thirty-five rounds of each combination were assembled in order to allow for possible equipment malfunctions to ensure that a minimum of 27 rounds was fired for record.

Firing of the rounds was done by configuration number, starting at configuration 1 and continuing to configuration 8. The results are shown in table 3. It is evident that the variation in time-to-peak pressure is affected by the factors chosen. In the M80 round, variation of time-to-peak pressure, including all factors, was 132.7 μs. For the M62 round, the variation of action time over all factors was 60.8 μs, less than half that of the M80 round. By using the standard M80 as a baseline for affects on the ammunition performance, it is easy to categorize the effects each factor had.

The standard M80 round (configuration 1) baselined at a time to peak pressure of 728.5 μs. As is shown in figure 2, there is an obvious delay in propellant ignition. By increasing the intrusion depth (configuration 2), which decreased the free-space volume within the case, the time to peak pressure decreased by 101.2 μs to 627.3 μs. Additionally, as can be seen in figure 3, the propellant ignition delay has disappeared. Retaining the original intrusion depth and replacing the primer with the M43 (configuration 3) resulted in a slower time-to-peak pressure, increasing this by 32 μs to 760.5 μs (fig. 4). Combining these two changes (configuration 4) results in essentially no change (fig. 5). While the step is not evident, the ignition rate has decreased. The average time to peak pressure decreased by 1.9 μs, but the increase in the standard deviation from 39.1 to 50.0 more than covers any improvement this may point to.

The same test was run for the M62. The baseline was the standard M62 cartridge (configuration 6), with a time-to-peak pressure of 573.6 μs. Figure 6 illustrates the classical P-T trace of the M62. By decreasing the intrusion depth of the tracer bullet to equal that of the M80 (0.40 in., configuration 5), the time-to-peak pressure increased to 674.9 μs, an increase of 101.3 μs. Figure 7 shows the slower pressure increase this change caused. Retaining the original intrusion depth and replacing the M34 primer with the M43 (configuration 8) resulted in the time-to-peak pressure increasing by 40.5 μs over the standard M62. By changing both the intrusion depth and the primer (configuration 7) resulted in a time-to-peak pressure of 614 μs, a net increase in time to peak pressure of 99.7 μs. Full factorial test data is shown in appendix A.

**Propellant Verification Tests**

During this test, 15 rounds of standard M62 tracer and 15 rounds of standard M80 ball rounds were fired. As previously seen, the average time-to-peak pressure was markedly different with the M62 reaching its peak 140 μs faster than the M80 (table 4). Also, the average peak pressure for the M62 round was higher - 50,160 psi versus 44,577 psi for the M80.

The follow-on firing was done with the bullets switched between the two cartridges and assembled to a nominal length of 2.80 in. This meant the M80 cartridges now had the M62 bullet and an intrusion of 0.58 in. The M62 cartridge now had the M80 bullet and an intrusion depth of 0.40 in. In this test, in both categories, the M62 bullet/M80 case performed as well or better than the standard M62 tracer and the M80 bullet/M62 case performed worse than the standard M80. The M80 bullet/M62 case combination had an average peak pressure of only 41,407 psi, as compared to the 44,577 psi of the standard M80 round. Although the peak pressure was less than that of the M80, it took 55 μs longer to reach that pressure. Conversely, the M62 bullet/M80 case combination proved better propellant performance (approximately 1,400 psi higher case mouth and 21 μs faster time) than the standard M62.

The final tests in this series were the nose and base tap tests. This attempted to determine whether it was the primer that was not giving enough impetus to the propellant by governing the position of the propellant within the case. This test had the opposite results of what would be expected had the problem originated with the primer. Namely, the nose tap tests, which moved the propellant forward in the case and away from the primer, experienced better time-to-peak pressures and higher case mouth pressures than the base tap test. The base tap resulted in a 1,300 psi reduc-tion in case mouth pressure and an 18 μs increase in time-to-peak pressure. However, it is felt that no definite conclusions should be drawn from the nose and base tap results, since the action times were well within one standard deviation of each other. Complete data is listed in appendix B.

## TASK ORDER CONTACT

### Phase I

Two propellants were identified for this test:

- WC749 – a slightly less dense propellant that eliminates the free-space volume in the case while maintaining the same velocity as the WC846. Potassium sulfate is used as the surface coating for this propellant.

- WC846 flash suppressed – which differs from the WC846 ball propellant in that it has a potassium sulfate surface coating instead of calcium carbonate. This surface coating adds energy to the burning of the propellant rather than take away energy as the calcium carbonate does.

Additional configurations were assembled as listed below for control purposes:

- WC846 ball propellant – to act as a control to compare with the hand assembled cartridges

- WC846 ball propellant with hollow fill – this configuration also acted as a control. The base propellant was used while eliminating the free-space volume

- Reference cartridges – to act as a control

In order to identify any difference between the two propellants, the contractor assembled 90 cartridges of each ball round for testing at a temperature of -65ºF. All were assembled to an overall length of 2.80 - 0.03 in., for a total of 450 rounds. The cartridge components were the same as those employed in the standard M80 ball round, excluding the propellant as described previously.

After assembling the cartridges, the contractor waterproofed the cartridges as shown in drawings 10521998 and 10523088 from the M80 technical data package. Each cartridge was drilled 0.75 in. from the head of the cartridge case. A pressure barrel was modified as shown in figure 11 for mid-case pressure tests. Correspondingly, the case was drilled 0.75 in. from the head.

### Phase II

The test was performed as just outlined. A new test barrel was modified for the mid-case pressures since the first barrel was beginning to show signs of erosion near the mid-case port.

The groups of rounds were fired in a somewhat randomized fashion to reduce the possibility of equipment problems appearing as ammunition trends. The firing order was as shown in table 6. Note that the limited number of rounds available (due to a change in scope without a corresponding increase in funding) resulted in the number of rounds for testing at each temperature not being identical.

Also of note is that the peak pressures measured were mid-case not case mouth, so the peak pressures appear higher than the allowable limit of 52,925 psi but are not comparable. Also, due to limitations in the test equipment at LCAAP, the time measured to partial peak pressure is at 25% of peak pressure rather than the 17,000 psi measurement from ARDEC testing. This 25% of peak pressure corresponded to an average value of 12,885 psi.

As shown in table 6, phase II tested the rounds at three temperatures: -65°F, +70°F, and +155°F. Both WC846 and WC846FS propellant were used during this series of tests, the WC846 as a reference. The rounds were both hand assembled. As tested, the flash suppressed propellant consistently gave higher mid-case pressures. The differences were between 570 psi at -65°F to 2,437 psi at +155°F. The overall variation with the WC846 was 6,251 psi, as compared to 6,826 psi for the WC846FS, a difference of 575 psi. The tests for pressure verified that the propellant was a reasonable alternative to the WC846. However, the real test is the time-to-peak pressure.

The time-to-25% of peak pressure was found for both the WC846 and the WC846FS. The time to the measured pressures were consistently lower for the WC846FS. At a temperature of +155°F, the measure time shows a difference of 43 µs. At ambient and cold, the difference in action time is 87 µs and 78 µs, respectively. Bearing in mind that this is to 25% of peak pressure, this is noteworthy. First, the difference at +155°F is 43 µs. The difference between -65°F and +155°F was 78 µs.

### Phase III

Phase III was simply a build phase. One hundred forty thousand rounds were produced and shipped to the ATC. Lot acceptance testing at the plant was conducted per the normal practice.

## DISCUSSION

### Factorial Testing

From the factorial tests, it appears that the only factor that positively influences the time-to-peak pressure with the M80 was that of the intrusion depth. Changing the primer increased the time to peak pressure and changing both intrusion depth and the primer resulted in essentially no change. This leads us to believe that the intrusion depth is the most important factor in the time-to-peak pressure.

From the M62 factorial tests, again, it appears that the factor that provides the greatest change in time-to-peak pressure was that of the intrusion depth. By changing the primer, or changing the primer and the intrusion depth together increased the time-to-peak pressure. It is also interesting to note that when the intrusion depth was changed for the M62 and the M80, the increase in time-to-peak pressure is nearly the same as the difference between the M80 and M62: 101.3 µs increase for the M62 with the increased free-space volume and 101.2 µs for the standard M80 as compared to the M62.

By changing the intrusion depth, the net effect was actually to change the free-space volume within the cartridge. In theory, a more densely packed propellant yields a faster burn rate. The factorial experiment seemed to prove this out. A statistical analysis was conducted that supports this conclusion (app C).

However, rather than accept this at face value, it was decided to further investigate. The follow-on test (the bullet switch and the nose and base tap tests) was done to ensure that the differences in the percentage of calcium carbonate (0.30 to 0.65% for the ball ammunition and a maximum of 0.25% for the tracer ammunition) in the WC846 propellant did not have an effect on the performance of the round. Pressure was taken at case mouth.

**Propellant Confirmation Test**

The propellant confirmation test used 15 rounds of each configuration to determine what effect the propellant had on the action time. In the factorial tests, the propellant always followed the bullet. The concern was that this might mask differences in the WC846 propellant due to differences in the calcium carbonate levels. The bullet switch test was conducted to address this issue.

For the bullet switch test, the bullets for the standard rounds were pulled from their cases and reinserted. This would eliminate the bullet pull as a variable. First, the standard M80 ball round was fired. The time-to-peak pressure (case mouth) was 743.1 µs, with a standard deviation of 55.6 µs. The standard M62 round had a time-to-peak pressure of 603.2 µs with a standard deviation of 45.5 µs. This is a difference of 139.9 µs. When the M62 projectile was put into the M80 case, the time to peak pressure was 582.9 µs with a standard deviation of 33.2 µs. Notice that there was no increase in action time with the propellant used in the M80 round. This confirms that the propellant is not a factor. When the M80 ball round was assembled with the M62 tracer case, the action time as compared to the standard configuration increased by 55 µs (approximately 1 standard deviation). The change over the standard M62 cartridge was 195 µs.

From this test, it was determined that it is not the difference in propellant type that caused the difference in action time.

In the tap tests, the first round fired was a series of reference M80 rounds to establish a base line. These values were to be compared to the nose and base tap rounds. As can be seen in table 4, the time-to-peak pressure (case mouth) was 675.6 µs with a standard deviation of 29.4 µs. When M80 rounds were given a nose tap, the time-to-peak pressure was 676.9 µs and the standard deviation was 49.5 µs. When the rounds were given a base tap, the time-to-peak pressure increased to 695.1 µs, with a corresponding standard deviation of 38.5 µs. The difference between the two tests is negligible considering that the difference in time-to-peak pressure is less than one standard deviation.

**Phase I Testing**

Phase I testing was conducted at LCAAP as outlined in the approach section. For each of the configurations, 90 rounds were fired single shot, in groups of 30. Peak mid-case pressure, action time[1], port pressure and velocity were measured for all the cartridge configurations. A summary of

[1]Action time for phase I testing is defined as the time measured from primer indent to 25% of peak pressure. This pressure is a point at which primer initiation effects are considered complete.

the data is shown in table 5. The following discussion does not include the reference or hollow filled round since the hollow filled round is not a viable contender for production and the reference rounds represent rounds that were produced on a production line, and not by hand. The average peak pressure varied between a low of 29,720 psi for the WC749 and a high of 38,016 psi for the WC846. On port pressures, the high was for the WC749 at 8,889 psi while the WC846 registered the low with 8,534 psi. Action time to 25% of these pressures showed the WC749 and the WC846FS propellants yielded an improvement over the WC846 propellant of 107 μs and 93 μs, respectively. Statistically, testing for the significance between the means[2] showed that at a 99% (t=0.005) level of significance, the difference between the WC749 and the WC846 was significant. Similarly, the difference between the WC846FS and the WC846 was significant. There was no perceived difference between the WC749 and the WC846FS. To better demonstrate the difference between the WC749 and the WC846FS, the action times were "normalized" to a pressure of 12,000 psi. This was done by the following method. The average peak mid-case pressure for each configuration was established. Each individual action time was then divided by the individual peak mid-case pressure value times 25% (the value LCAAP used to give time) to give a sec/psi value. This was then multiplied by the desired pressure (in this case 12,000 psi). At this point, the variance in peak pressure was no longer an issue. This method can be shown by the formula

$$NAT=[AT/ (PP*FP)]\, PD$$

where

NAT: Normalized action time
AT: Action time (in this case, the time to 25% of peak mid-case pressure)
PP: Peak (mid-case) pressure
FP: Fraction of pressure measured (25% of peak mid-case pressure)
PD: Pressure desired

Using this method, it was determined that there was a significant difference between the WC846FS and the WC846, but not the WC749 and the WC846. There also was a significant difference between the WC749 and the WC846FS. The significant difference was determined using a difference between the means test, where a z-score is found and compared to a nominal value. The z-score was calculate as follows

$$Z = (X_1 - X_2) / [(S^2/N)_1 + (S^2/N)_2]^{1/2}$$

where

$X_1$ = the average pressure with WC846FS at a given temperature
$X_2$ = the average pressure with WC846 at the same temperature
S = the standard deviation for the respective groups
N = the number of rounds in each group

In order for the differences to be considered significant, the z-score had to be greater than 2.576[3]. This corresponds to 99.5% of all times-to-peak pressure will be equal to or quicker than the WC846 propellant. From this analysis, it was determined that the difference between the WC846FS

[2]Freund & Williams, Elementary Business Statistics: The Modern Approach, 4th ed.

[3]Ibid.

and the WC846 was significant. However, it also showed that the WC749 and the WC846 was significant. But due to the difference in peak pressures, an allowance had to be made to adjust for the difference. The values were normalized as discussed previously, and the action time was again subjected to a difference between the mean test. This time it was found that the difference between the WC749 and the WC846 was not significant, but the difference between the WC846FS and the WC846 was significant.

From this analysis, it was determined that phase II would continue with the M80 cartridge with the WC846FS propellant configuration.

### Phase II Testing

Phase II testing centered on the cartridge configuration believed most promising from phase I, that of the M80 bullet and case loaded with the WC846 flash suppressed propellant. In order to be considered successful, the reduction in action time achieved by using the WC846FS as opposed to the WC846 ball propellant, a difference of at least 151.9 µs, would need to be demonstrated. This difference is the difference noted in the factorial testing between the M62 tracer ammunition and the M80 ball ammunition. This difference is considered the significant factor because in the factorial testing, no delay in propellant ignition was observed in the M62 pressure-time curve, whereas there was a delay seen in the M80 pressure-time curve. This delay appeared both as a step in the pressure increase curve and as a period of slow pressure growth. This delay in the pressure increase was typically accompanied by an average increase in action time of 151.9 µs. In phase I, decreasing the action time by this amount would be considered a successful elimination of this delay. Using the same test for difference between the means as in phase I, the z-score was again found at each temperature and it was found that the differences in the tests were significant. The z-score was calculated as in phase I. Based on these results, it was determined that the WC846FS offered enough of a decrease in action time to warrant entering into phase III.

However, it is of interest to note, that by coupling these changes in the average with the change in the standard deviation of the average action time as compared to the WC846, yields results that emphasize the change this new propellant represents. The WC846FS has standard deviations that are 44% lower at +155°F and 35% lower at +70°F than the WC846. At -65°F, the difference drops to 15%. Bearing in mind that hangfires in the M134 occur at very low rates, it is important to look at the average plus three (or more) standard deviations. When this is considered, and consideration is made that the action times in this study are actually time-to-25% of peak pressure, it is evident that a big difference in action time (primer indent to bullet exit) will be seen.

### Phase III Production

After phase II was completed, the analysis of the data confirmed that the M80 ball round with the flash suppressed propellant was still a promising candidate. Lake City Army Ammunition Plant was given the go ahead to produce rounds for the qualification tests at APG. Lake City Army Ammunition Plant produced 140,000 rounds and shipped them to APG for qualification testing.

## QUALIFICATION TESTS

The qualification testing conducted at APG was conducted from the end of May to end of September 1997. A summary of the tests conducted and the rounds fired for each of the tests is listed in table 7. The planned testing required a total of 106,480 rounds. To ensure that a

sufficient supply was available to conduct this test, 113,000 rounds were requested. The weapons used in this testing were the M240 and M60 machine guns (six each). Two rifles were also used: the M24 and the M14. The following tests were conducted: dispersion, pressure/velocity/actin time, function/casualty and reliability, environmental, cook-off, time of flight, toxic fumes, noise, and barrel performance.

The results of the qualification test confirmed that WC846FS propellant does not cause adverse effects on the weapons wherein the M80 ball is used. Results of this test are provided in the TECOM test report, "7.62-mm M80 Ball Cartridge"[4], project number 1-M4-000-M80-001.

## CONCLUSIONS

It is evident that the free-space volume in the M80 ball round is the major factor in the proper ignition of the propellant. Rather than changing the case to reduce volume or adding a fill that would be unique to the M80, the WC846FS propellant introduces a more consistent ignition without physically altering the cartridge. These results show great promise in addressing the M80 action time deficiencies, and bringing the action time more in line with that of the M62 tracer round. This is expected to greatly reduce the number of waivers necessary and malfunctions in the M134 mini-gun.

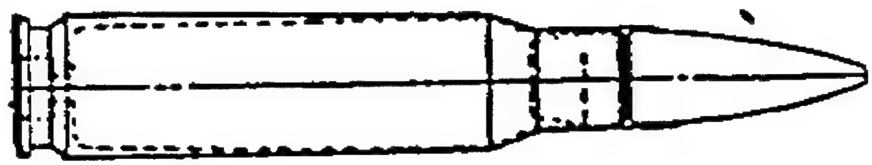
However, it should also be kept in mind that the required action time for the M80 round is 4.0 ms, which both the ball and tracer rounds currently meet.

## RECOMMENDATIONS

The M80 ball round has undergone qualification testing with the WC846FS propellant. This testing has shown that the WC846FS propellant is acceptable for use as a replacement for the WC846. An Engineering Change Proposal is being prepared to begin using this propellant in the production of M80 ball ammunition.

This propellant is currently used in the M276 dim tracer round. It is recommended that this propellant also be qualified for the M62 tracer to allow a single propellant to be used across the board for the M80 and M62 rounds.

[4]Steier, Gerald, "Production Qualification Test of 7.62mm, M80 Ball Cartridge (with Flash-Suppressed Propellant)," TECOM final report, January 1998.



Cartridge: 7.62mm, M80 Ball

BALLISTICS PERFORMANCE:

| | |
|---|---|
| Velocity | 2750 ± 30 ft/sec at 78 feet |
| Pressure | 50,000 psi, max |
| Accuracy | 5" Mean Radius @ 600 yds |

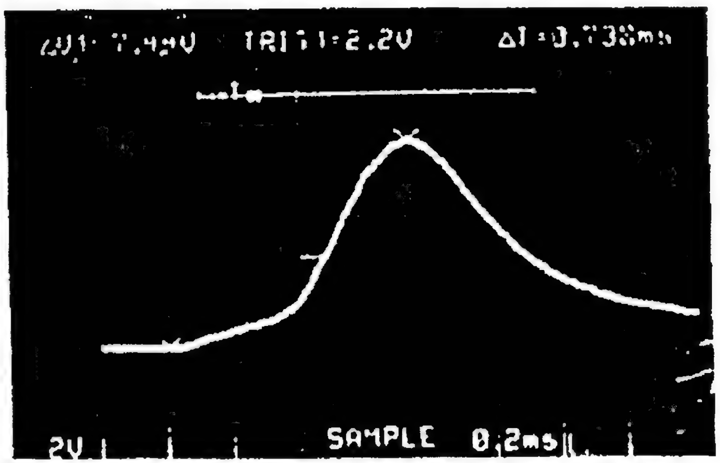
COMPONENTS:

| | |
|---|---|
| Cartridge Case | Brass |
| Bullet Jacket | Gilding Metal Clad Steel |
| Primer | #34 |
| Propellant | WC846 |

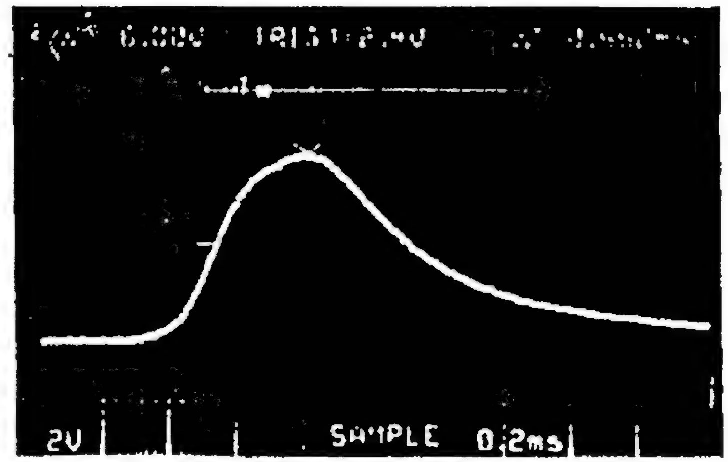
Figure 1
Cartridge, 7.62-mm NATO M80 ball

# TYPICAL PRESSURE-TIME CURVES

December 1992




M80 BALL AMMUNITION




M62 TRACER AMMUNITION

Figure 2
Pressure-time curves – M80 and M62

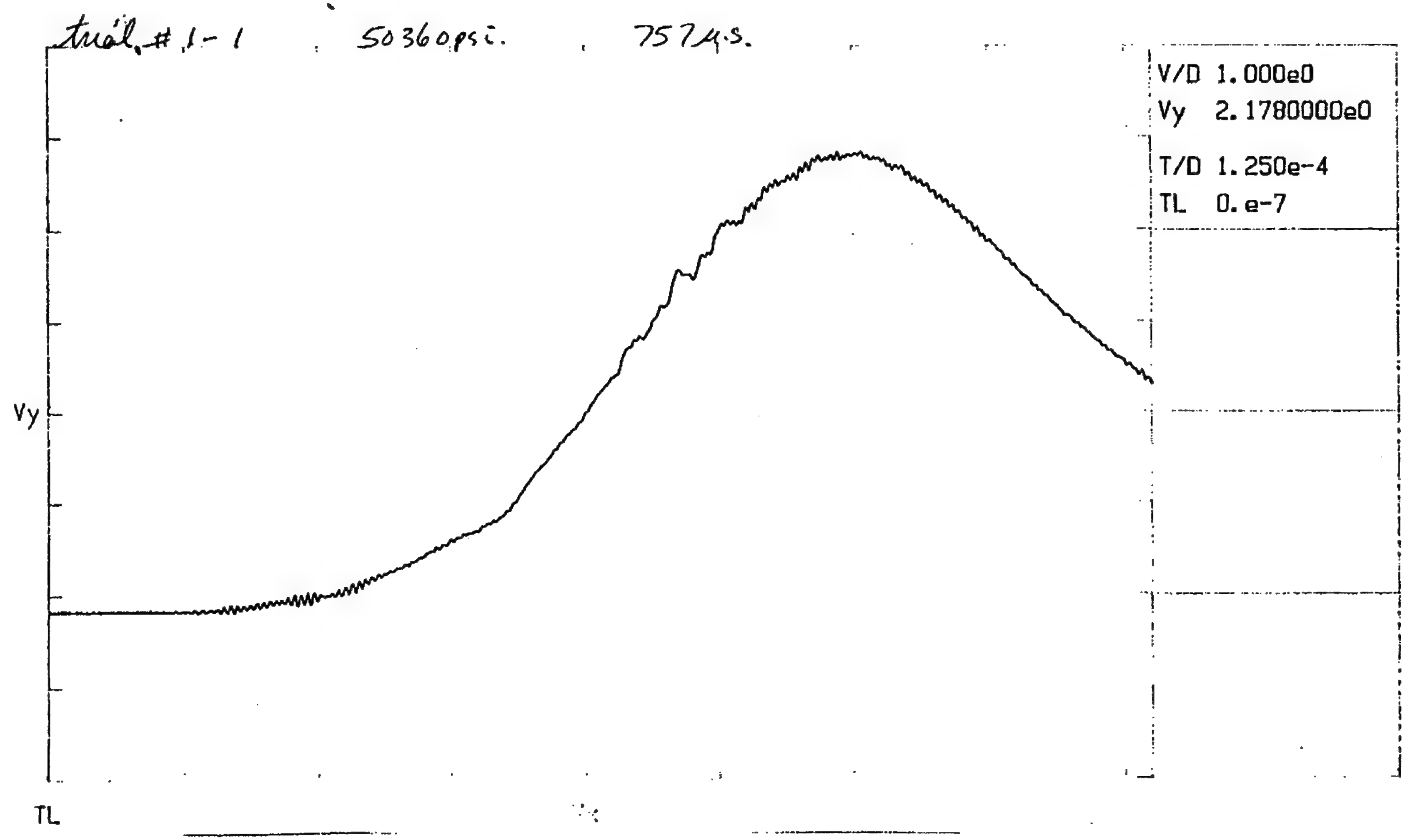



Figure 3
Mid-case P-T curve: standard M80 cartridge

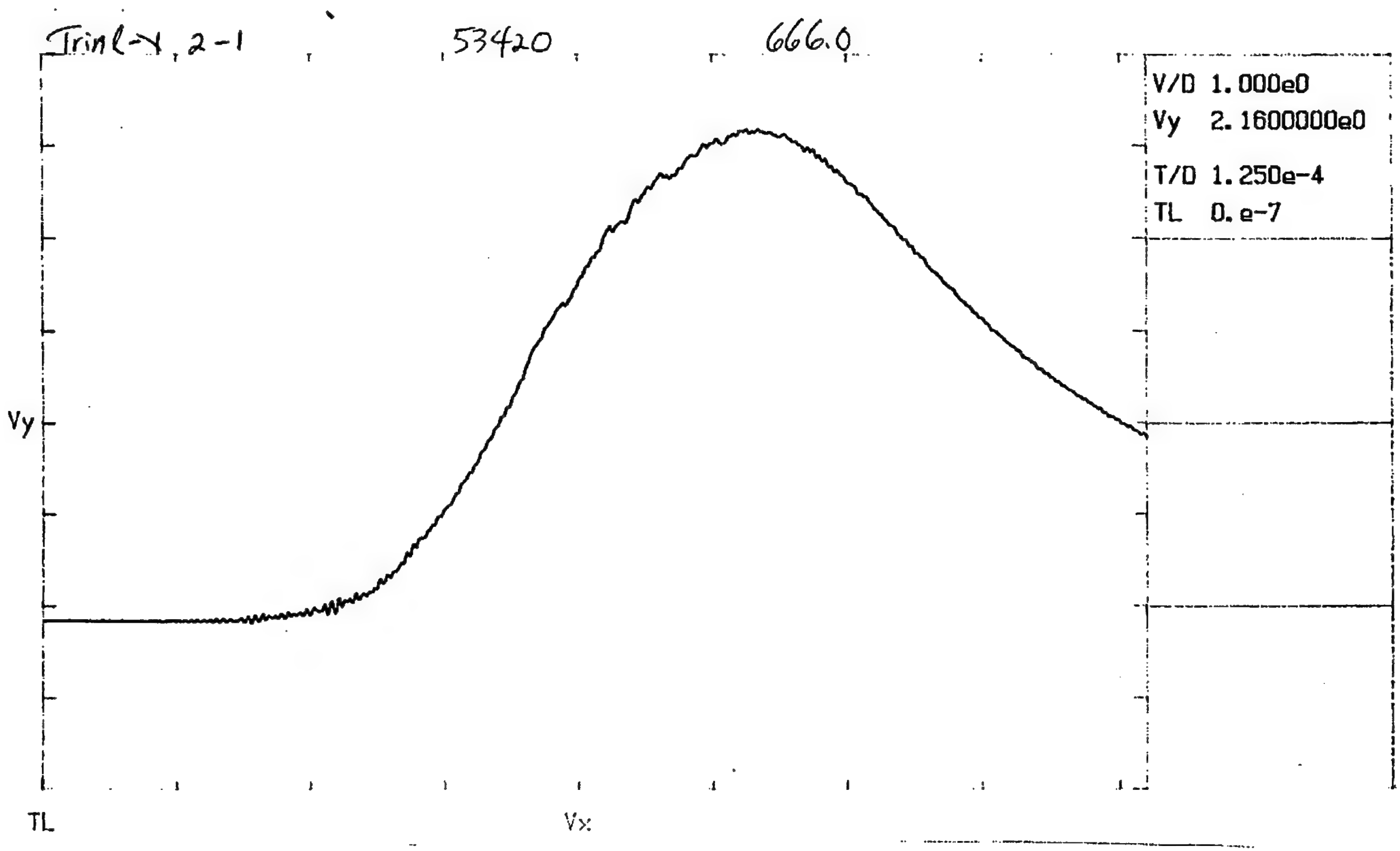



Figure 4
Mid-case P-T curve: M80 bullet, M34 primer, 0.57-in. intrusion

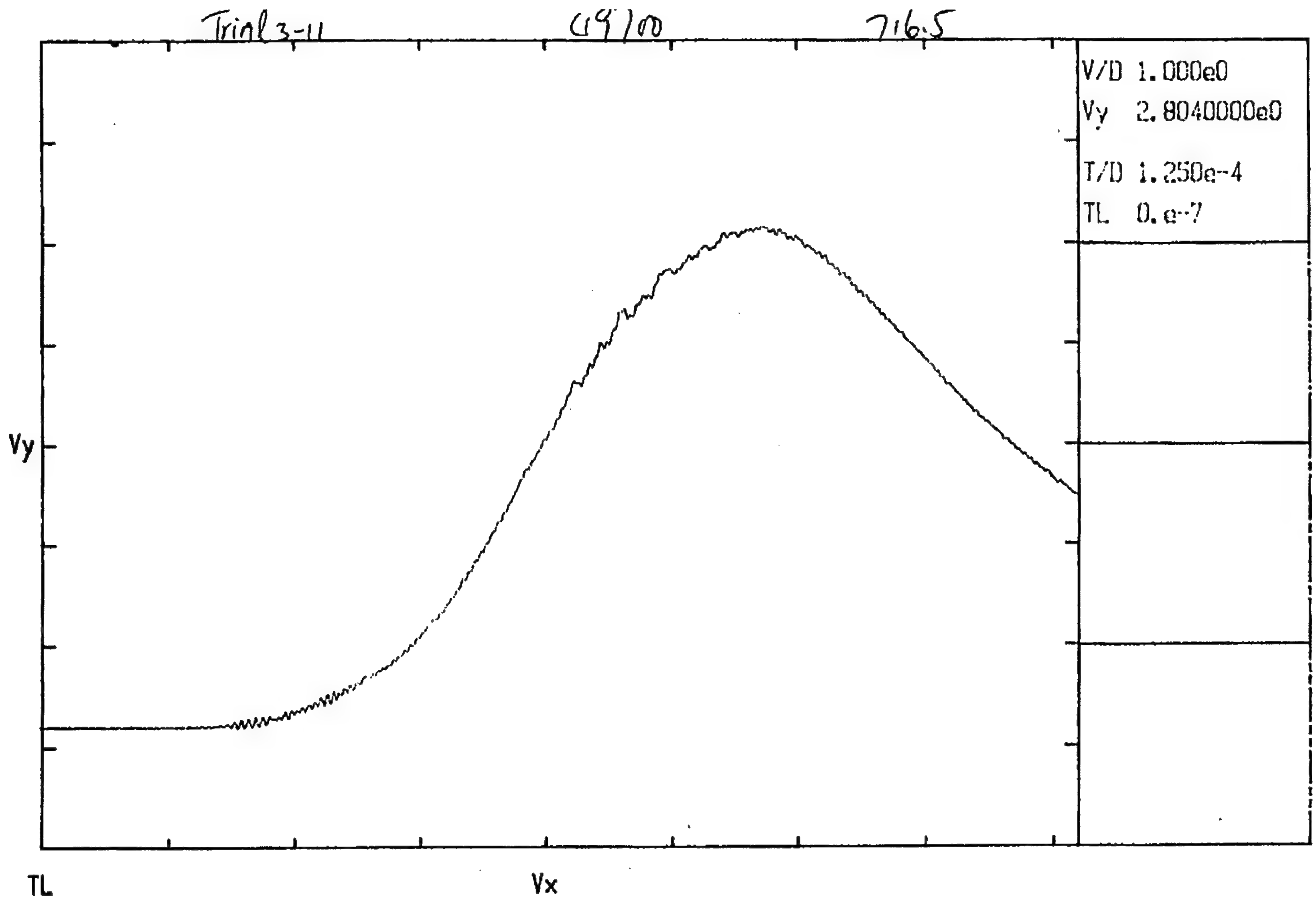



Figure 5
Mid-case P-T curve: M80 bullet, M43 primer, 0.40-in. intrusion

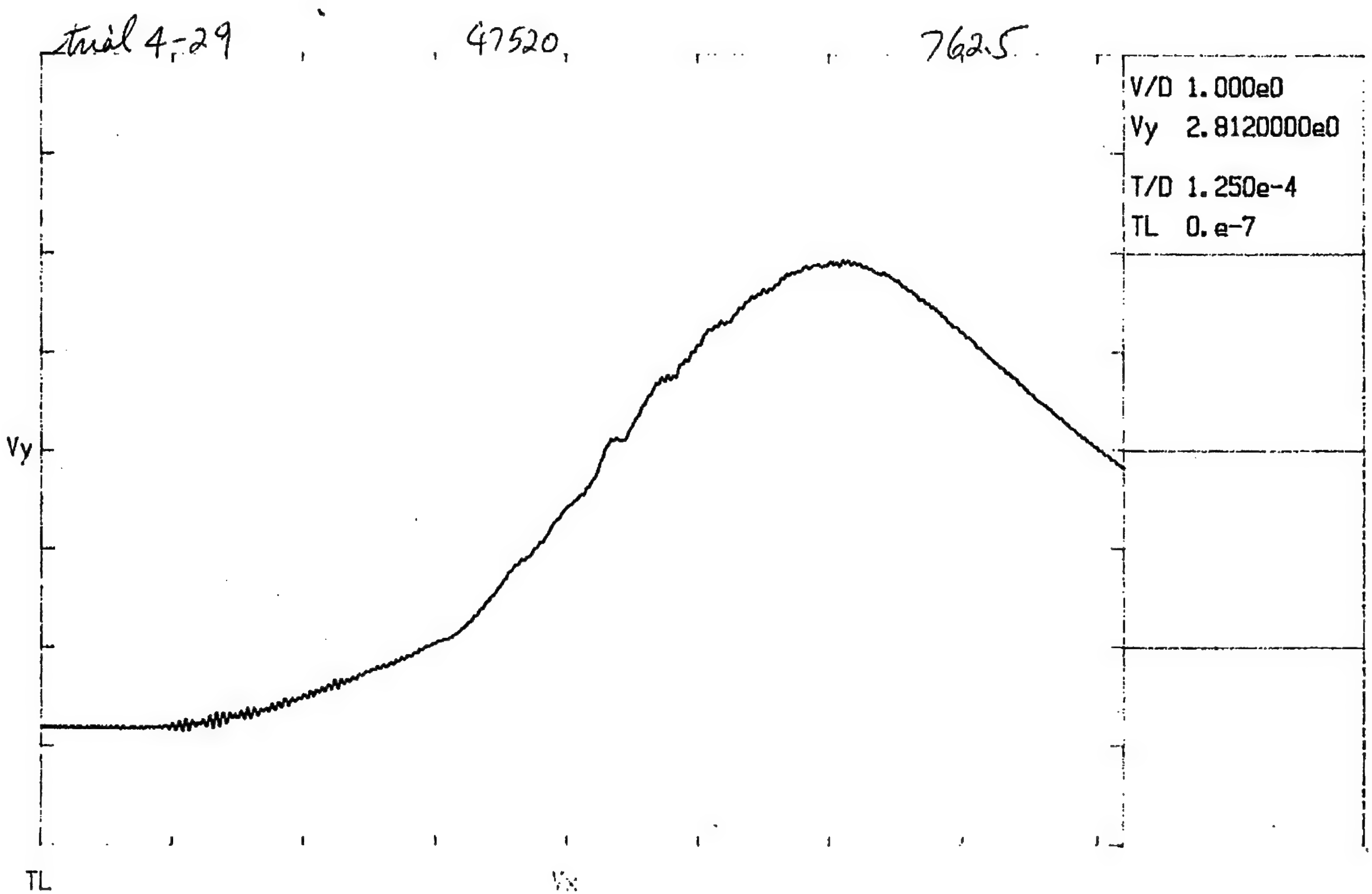



Figure 6
Mid-case P-T curve: M80 bullet, M43 primer, 0.57-in. intrusion

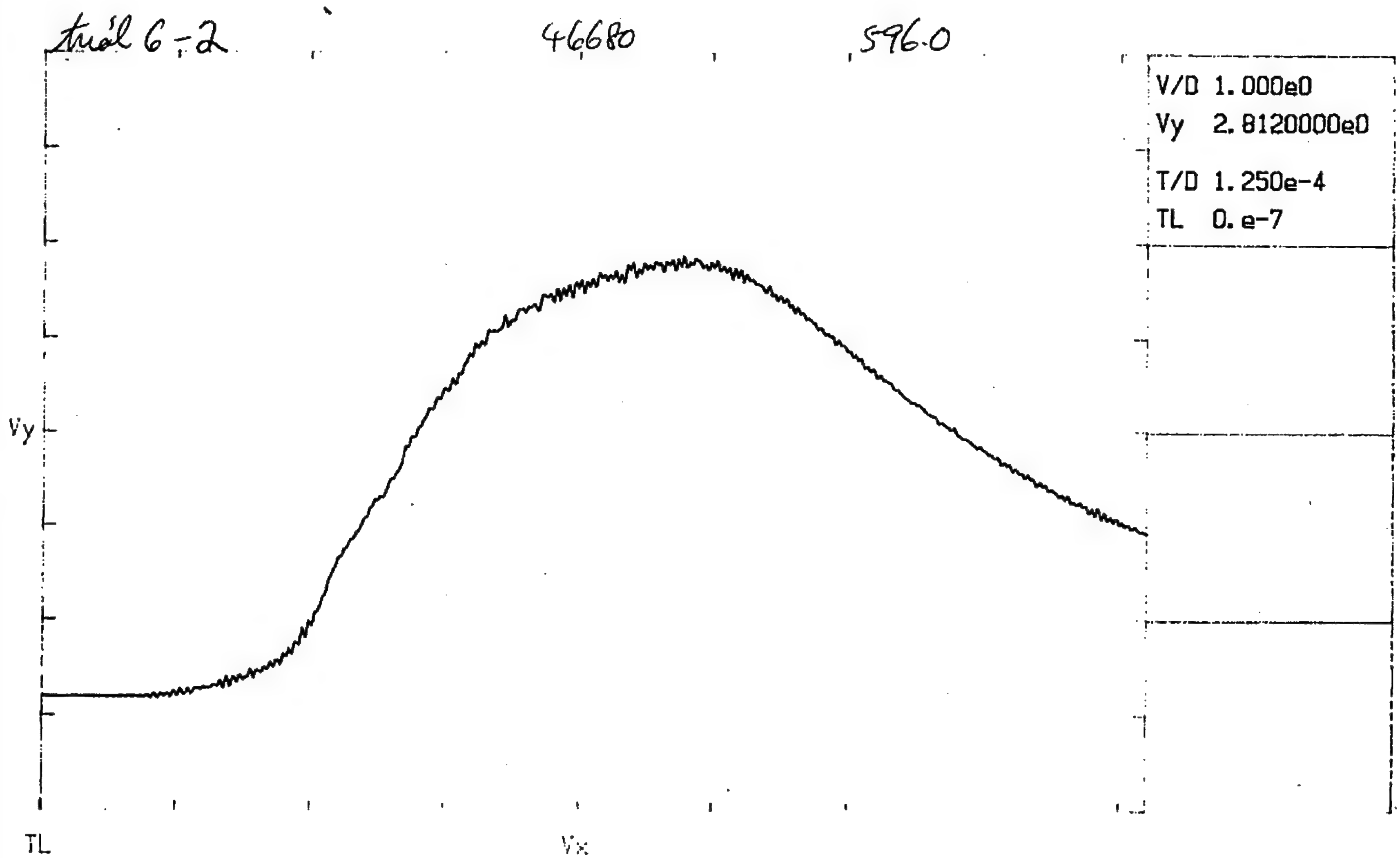



Figure 7
Mid-case P-T curve: M62 bullet, M34 primer, 0.40-in. intrusion

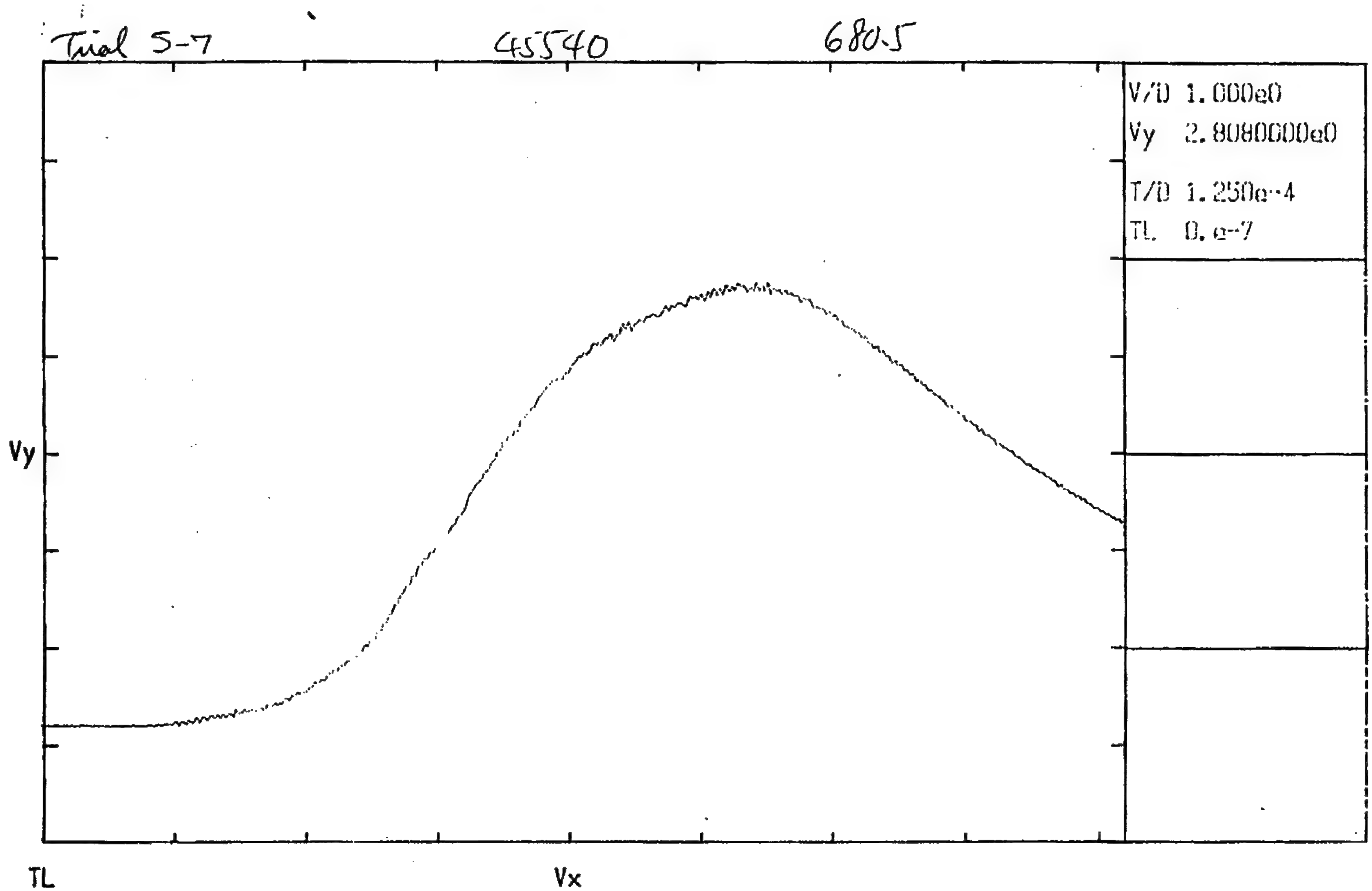



Figure 8
Mid-case P-T curve: standard M62 cartridge

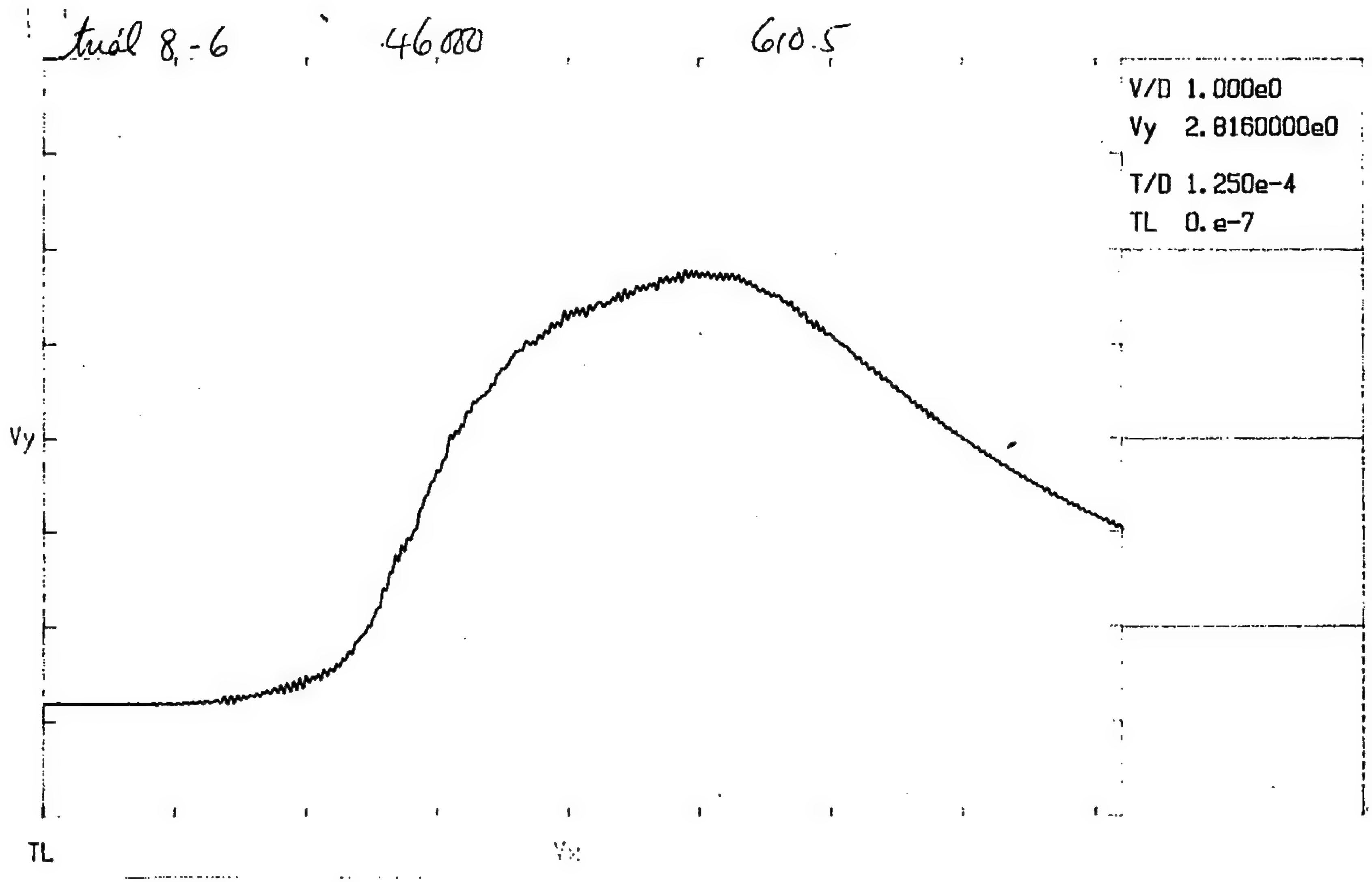



Figure 9
Mid-case P-T curve: M62 bullet, M43 primer, 0.40-in. intrusion

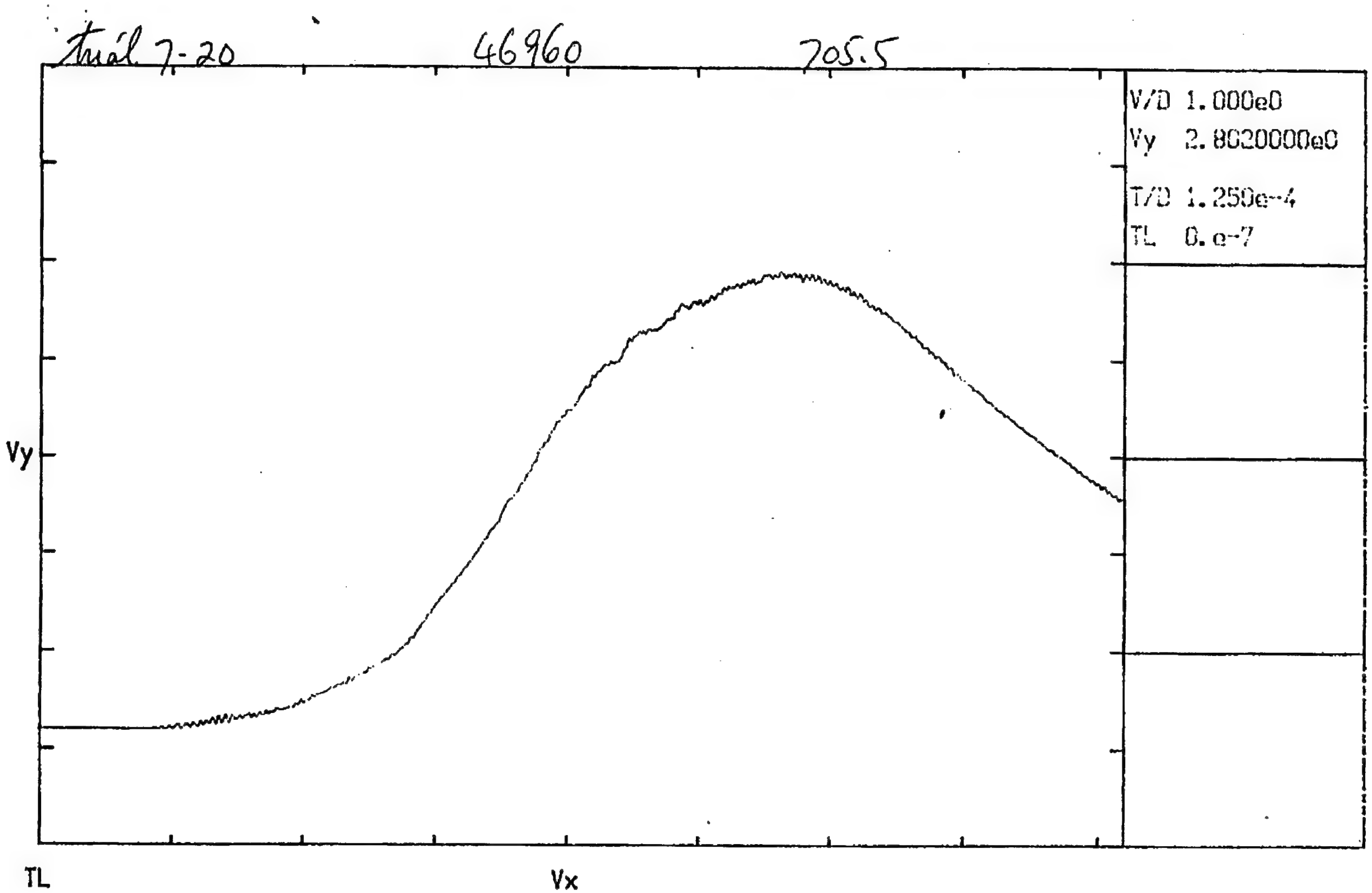
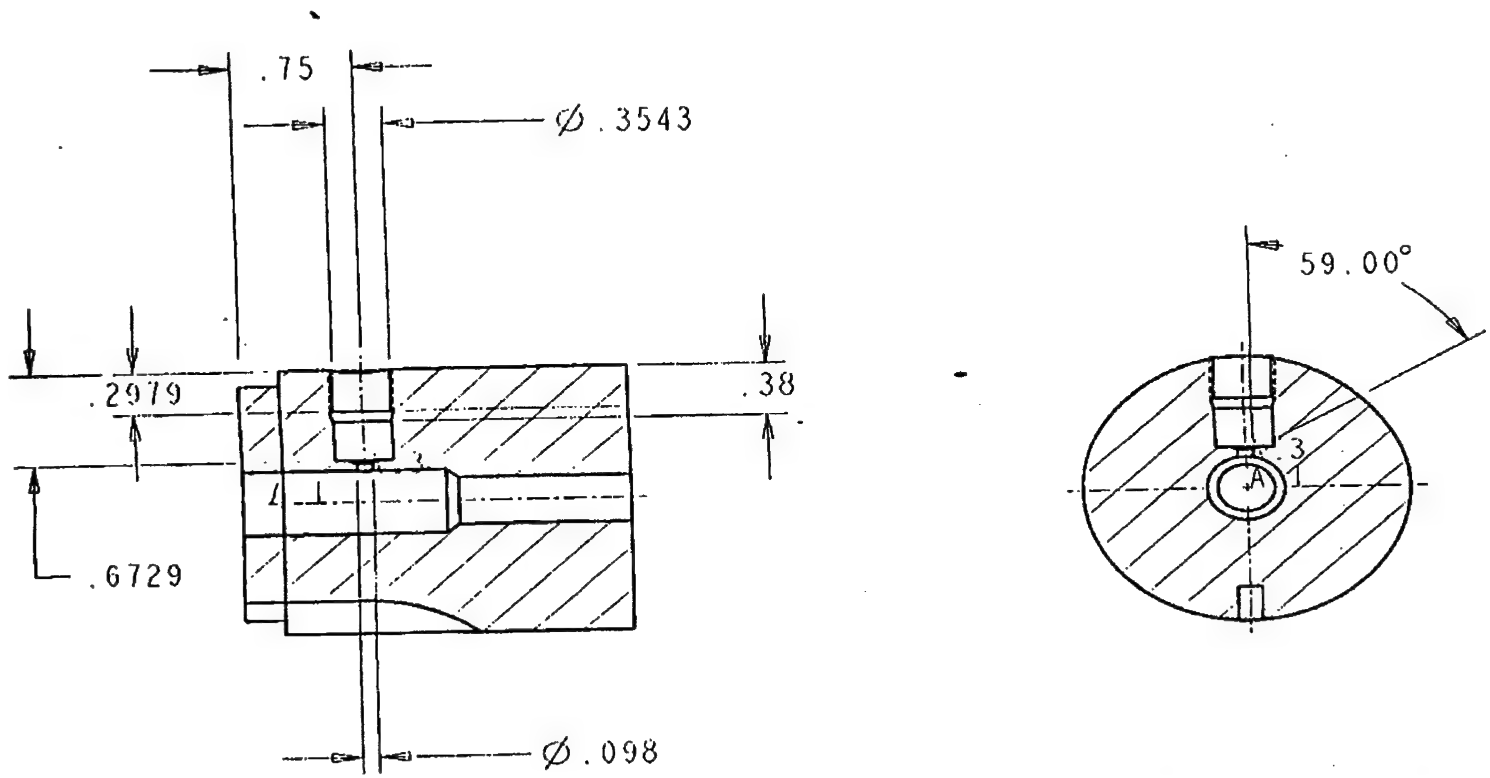


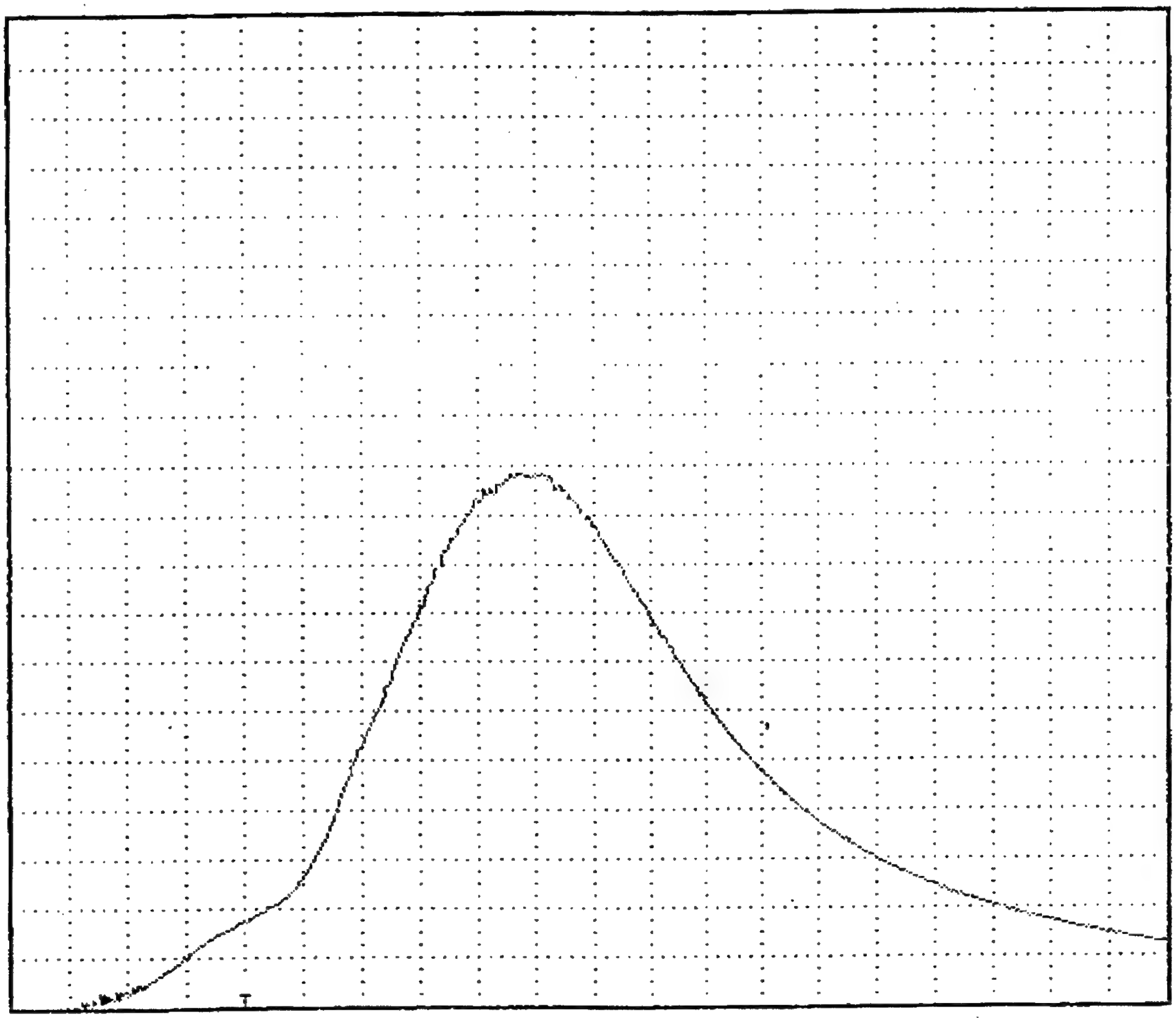

Figure 10
Mid-case P-T curve:  M62 bullet, M43 primer, 0.57-in. intrusion




NOTES:
1-ALTER VELOCITY TEST BARREL D7553791 AS SHOWN ON DWG. NO. 8649376. REPLACE CASEMOUTH TRANSDUCER TAP WITH MIDCASE TRANSDUCER TAP AS SHOWN.
2-DIMENSIONS ARE IN INCHES.

| | | |
|---|---|---|
| U.S. ARMY ARDEC<br>PICATINNY ARSENAL, NJ | | |
| BARREL, TEST, PRESSURE<br>MODIFICATION FOR MID CASE<br>PIEZOELECTRIC XDCR, 7.62MM | | |
| SIZE<br>A | CODE IDENT NO. | DRAWING NO.<br>762-01 |

Figure 11
Test barrel modifications

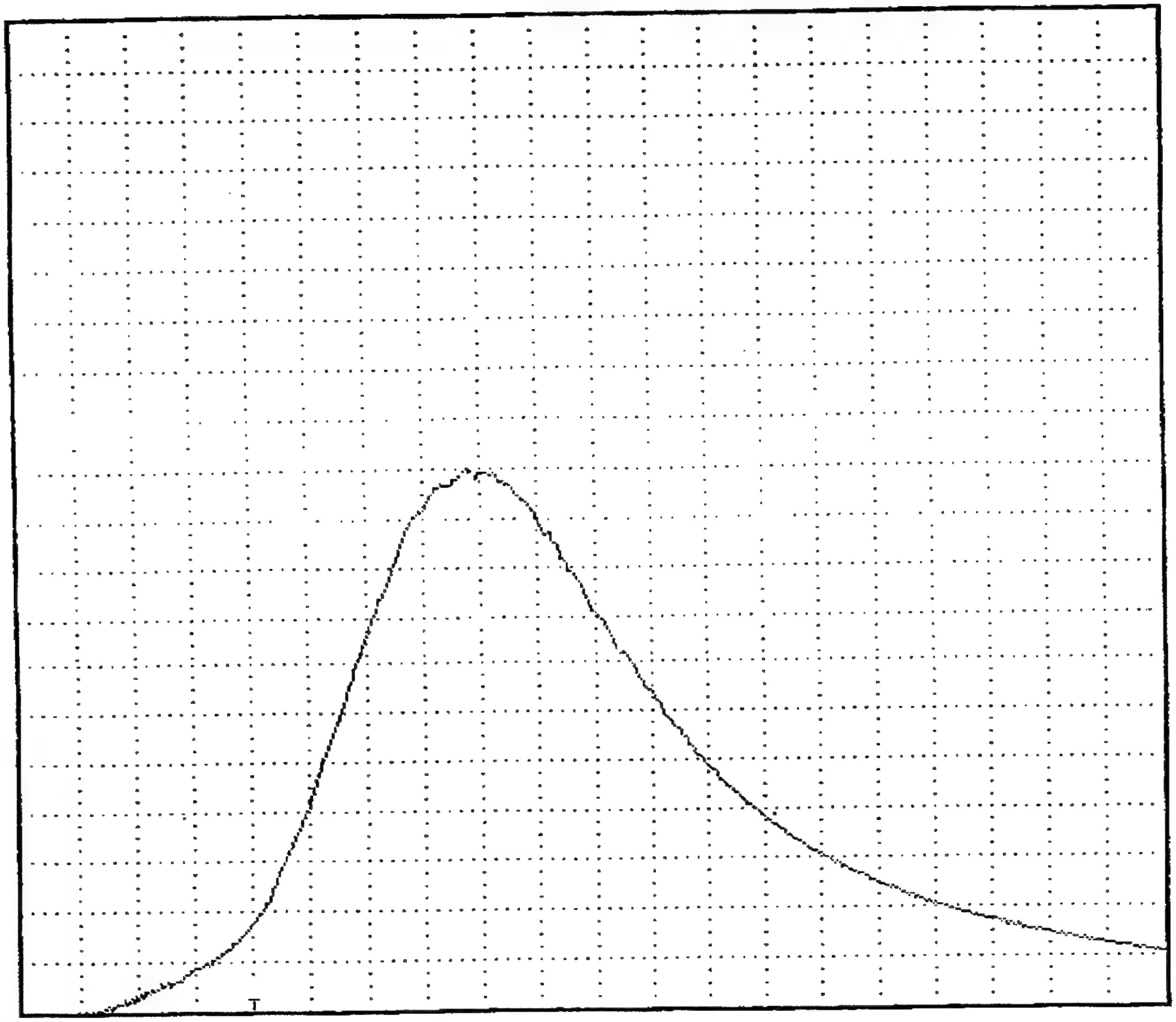


Curve #3 of File A:TEST3.CRV
3443 PSI per division and 100 microseconds per division
Plot includes offset of 0 PSI.

Time from FIRE to "T" trigger point = 384 microseconds.
Time from FIRE to "|" muzzle point = 13117 microseconds.

#1
WC 846
PL 49894

Figure 12
Phase I – typical P-T curve: WC846 propellant



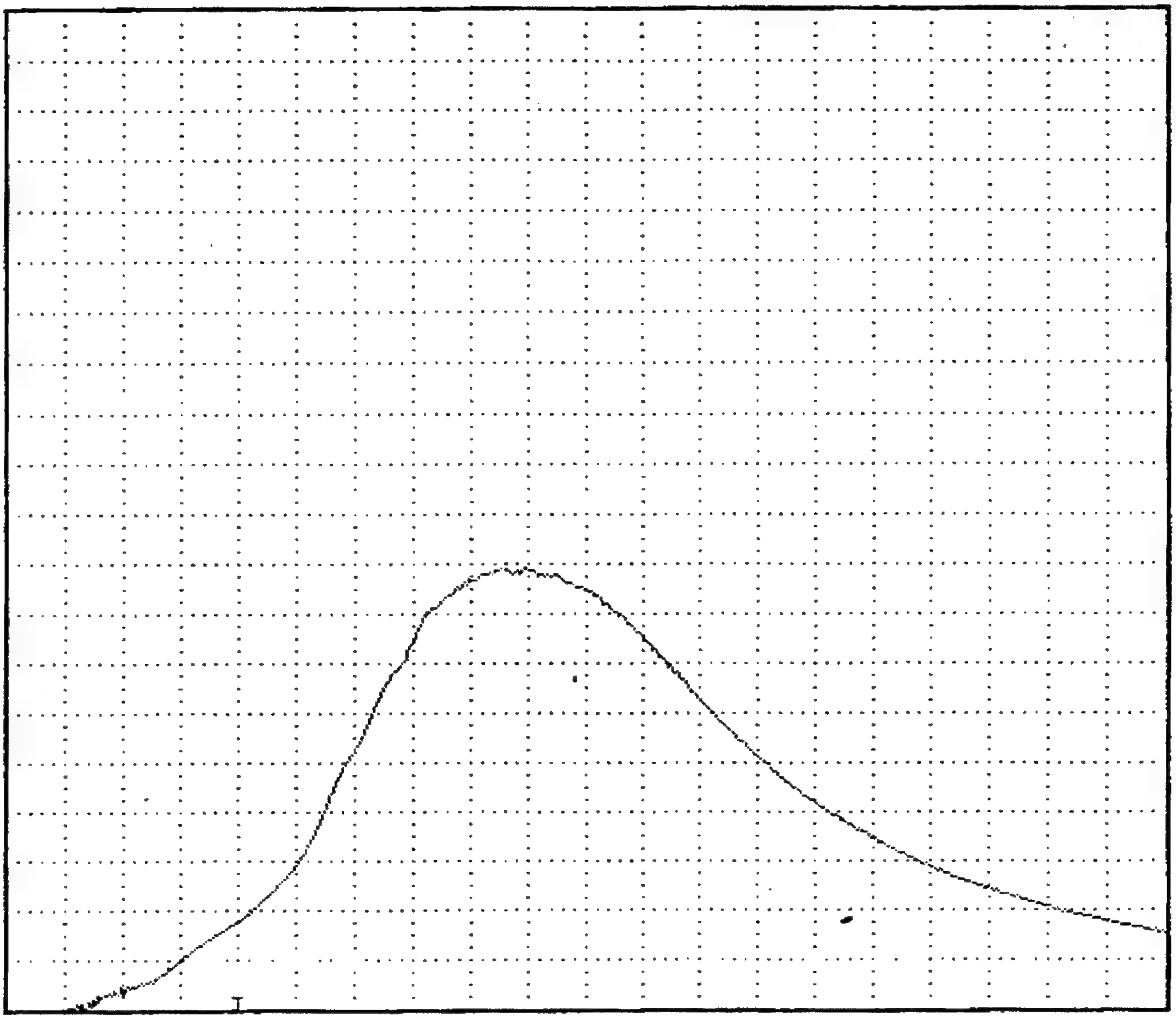

```
Curve #35 of File A:TEST2.CRV
  3443 PSI per division and 100 microseconds per division
  Plot includes offset of        0 PSI.

Time from FIRE to "T" trigger point =    378 microseconds.
Time from FIRE to "!" muzzle point  =  12883 microseconds.
```

#1 WC 846 FS,

F.L. 49883

Figure 13
Phase I – typical P-T curve: WC846FS propellant



Curve #7 of File a:test1.CRV
3443 PSI per division and 100 microseconds per division
Plot includes offset of 0 PSI.

Time from FIRE to "T" trigger point = 396 microseconds.
Time from FIRE to "¦" muzzle point = 13554 microseconds.

#1 WC 749

Figure 14
Phase I – typical P-T curve: WC749 propellant

Table 1
Factorial test matrix

| | M34 primer | | M43 primer | |
|---|---|---|---|---|
| | 0.40 intrusion | 0.57 intrusion | 0.04 intrusion | 0.57 intrusion |
| M80 bullet | Configuration 1 | Configuration 2 | Configuration 3 | Configuration 4 |
| M62 bullet | Configuration 5 | Configuration 6 | Configuration 7 | Configuration 8 |

Table 2
Effect of crimping on performance consistency

| Temperature | Ammunition Type | Mean Velocity (fps) | Velocity Std Deviation | Mean CM Pressure | Pressure Std Deviation |
|---|---|---|---|---|---|
| Ambient | Reference | 2,626 fps | 379 fps | 50,701 psi | 1,076 psi |
| | Crimped | 2,759 fps | 9 fps | 45,991 psi | 777 psi |
| | No Crimp | 2,515 fps | 575 fps | 47,815 psi | 3,724 psi |
| +125F | Reference | No Data | No Data | No Data | No Data |
| | Crimped | 2,800 fps | 12 fps | 53,903 psi | 1,594 psi |
| | No Crimp | 2,772 fps | 132 fps | 53,369 psi | 2,372 psi |
| -65F | Reference | No Data | No Data | No Data | No Data |
| | Crimped | 2,685 fps | 23 fps | 47,460 psi | 1,821 psi |
| | No Crimp | 2,677 fps | 26 fps | 47,705 psi | 2,130 psi |

Note: The M80 Ball rounds were assembled with a 0.57 inch intrusion

Table 3
Summary of factorial test data

| Config Number | Assembly | | | Action Time * (microsecond) | Std Dev of AT (microsecond) |
|---|---|---|---|---|---|
| | Bullet | Intrusion | Primer | | |
| 1 | Std M80 | 0.40 in | M34 | 728.5 μs | 39.1 μs |
| 2 | M80 | 0.57 in | M34 | 627.3 μs | 34.2 μs |
| 3 | M80 | 0.40 in | M43 | 760.5 μs | 48.3 μs |
| 4 | M80 | 0.57 in | M43 | 726.6 μs | 50.0 μs |
| 5 | M62 | 0.40 in | M34 | 674.9 μs | 29.2 μs |
| 6 | Std M62 | 0.57 in | M34 | 573.6 μs | 28.1 μs |
| 7 | M62 | 0.40 in | M43 | 673.3 μs | 34.5 μs |
| 8 | M62 | 0.57 in | M43 | 614.1 μs | 33.5 μs |

* Time to peak pressure

(a) Descending order

| Config Number | Assembly | | | Action Time * (microsecond) | Std Dev of AT (microsecond) |
|---|---|---|---|---|---|
| | Bullet | Intrusion | Primer | | |
| 6 | Std M62 | 0.57 in | M34 | 573.6 μs | 28.1 μs |
| 8 | M62 | 0.57 in | M43 | 614.1 μs | 33.5 μs |
| 2 | M80 | 0.57 in | M34 | 627.3 μs | 34.2 μs |
| 7 | M62 | 0.40 in | M43 | 673.3 μs | 34.5 μs |
| 5 | M62 | 0.40 in | M34 | 674.9 μs | 29.2 μs |

(b) Ascending order

Table 4
Summary of propellant conformation tests

| Test | Test cartridge configuration | Avg peak pressure (psi) | Std dev (psi) | Time-to-peak press (μs) | Std dev (μs) |
|---|---|---|---|---|---|
| Standard | M80 reference | 48,578 | 1.476 | 67.6 | 29.4 |
| | | | | | |
| Standard | Standard M80 ball | 44,577 | 1,456 | 743.1 | 55.6 |
| Bullet switch | M80 bullet/M62 case & propellant | 41,407 | 1,194 | 798.2 | 44.0 |
| | | | | | |
| Standard | Standard M62 tracer | 50,160 | 1,632 | 603.2 | 45.4 |
| Bullet switch | M62 bullet/M80 case & propellant | 51,553 | 1,232 | 582.9 | 33.2 |
| | | | | | |
| Nose tap | Standard M80 ball rounds | 47,111 | 1,854 | 676.9 | 49.5 |
| Base tap | Standard M80 ball rounds | 45,807 | 1,036 | 695.1 | 38.5 |

Table 5
Summary of phase I test data

| | Defined name | Values: Misc. | Given: | |
|---|---|---|---|---|
| Avg of all peak pressures: | AAPP | 35,273 psi | | For information only |
| Normalizing pressure: | NORMPRESS | | 12,000 psi | |
| Percent peak pressure | PPP | | 25% | Assigned by LCAAP |
| Level of significance | Z | Table II stats | 2.576 | (0.01 level of sig; = t-0.005 |

| | | | | Average | |
|---|---|---|---|---|---|
| Propellant: | Action time* (μs) | Std dev (μs) | AT+3SD (μs) | Peak press (psi) | Velocity (m/s) |
| WC749 | 424 | 65 | 620 | 29,720 | 2,279 |
| WC846FS | 438 | 59 | 614 | 35,852 | 2,350 |
| WC846* | 531 | 80 | 772 | 38,016 | 2,409 |
| WC846HF | 431 | 70 | 639 | 37,499 | 2,365 |
| Reference | 320 | 76 | 547 | 34,233 | 2,299 |
| Minimum: | 424 | 59 | 614 | 29,720 | 2,279 |
| Maximum: | 531 | 80 | 772 | 38,016 | 2,409 |

| Difference between means: | Action time* | |
|---|---|---|
| WC749 & WC846: | z = -9.84 | significant |
| WC846FS & WC846: | z = -8.94 | significant |
| WC749 & WC846FS: | z = -1.45 | not significant |

| | | | | Average | |
|---|---|---|---|---|---|
| Propellant: | Action time* (μs) | Std dev (μs) | AT+3SD (μs) | Peak press (psi) | Velocity (m/s) |
| WC749 | 686 | 108 | 1009 | 29,720 | 2,279 |
| WC846FS | 585 | 78 | 819 | 35,852 | 2,350 |
| WC846 (#) | 671 | 102 | 976 | 38,016 | 2,409 |
| WC846HF | 551 | 90 | 822 | 37,499 | 2,365 |
| Reference | 448 | 91 | 722 | 34,233 | 2,299 |
| Minimum: | 585 | 78 | 819 | 29,720 | 2,279 |
| Maximum: | 686 | 108 | 1009 | 38,016 | 2,409 |

| Difference between means: | Action time* | |
|---|---|---|
| WC749 & WC846: | z = 0.97 | not significant |
| WC846FS & WC846: | z = -6.39 | significant |
| WC749 & WC846FS: | z = 7.22 | significant |

*This represents the time it takes to get to a pressure equal to the Normalizing Pressure (NormPress).
#One data point was modified downward to bring the values more closely in line with the rest.

Table 6
Phase II test matrix

DRILLED CASES

| Propellant | Test | Temperature | Firing Order |
|---|---|---|---|
| | Mid-Case Pressure, | Cold (-65F) | 8 |
| WC846FS | Action Time, and | Ambient (70F) | 2,3,4,6,7 |
| | Muzzle Velocity | Hot (155F) | 10,11,12,14,15 |
| | | | |
| | Mid-Case Pressure, | Cold (-65F) | 9 |
| WC846 | Action Time, and | Ambient (70F) | 1,5 |
| | Muzzle Velocity | Hot (155F) | 13 |

NON-DRILLED CASES

| Propellant | Test | Temperature | No. Of Rounds |
|---|---|---|---|
| | Mid-Case Pressure, | Cold (-65F) | 15 |
| WC846FS | Action Time, and | Ambient (70F) | 5,6,7,8,9 |
| | Muzzle Velocity | Hot (155F) | 10,11,12,13,14 |
| | | | |
| | Mid-Case Pressure, | Cold (-65F) | 4 |
| WC846 | Action Time, and | Ambient (70F) | 1,2 |
| | Muzzle Velocity | Hot (155F) | 3 |

Table 7
Phase II analysis of results

Mid-Case Action Times (to 25% of Peak Pressure)

| | Defined Name | | Value | Notes |
|---|---|---|---|---|
| Avg of all Peak Pressures: | AAPP | | 51,539 psi | Information only |
| Normalizing Pressure: | norm_press | | 12,885 psi | 12,000 psi |
| Percent Peak Pressure: | ppp | | | 25% |
| Level of Significance | z | | 2.576 | Table II Stats |

| | Data as Tested | | | Average | |
|---|---|---|---|---|---|
| Propellant & Temperature | Action Time | Std Dev (1) | AT+3SD | Peak Press | Velocity |
| WC846 +155 | 379 µs | 52 µs | 535 µs | 52,086 psi | 2,673 m/s |
| WC846 +70F | 424 µs | 48 µs | 568 µs | 53,378 psi | 2,726 m/s |
| WC846 -65F | 441 µs | 53 µs | 600 µs | 47,127 psi | 2,579 m/s |
| WC846FS +155 | 336 µs | 29 µs | 421 µs | 54,523 psi | 2,726 m/s |
| WC846FS +70F | 337 µs | 31 µs | 431 µs | 54,423 psi | 2,753 m/s |
| WC846FS -65F | 363 µs | 45 µs | 498 µs | 47,697 psi | 2,601 m/s |

| Difference between means: | z-score | Assessment |
|---|---|---|
| WC846 & WC846FS +155 | z = 4.44 | significant |
| WC846 & WC846FS +70 | z = 12.91 | significant |
| WC846 & WC846FS -65 | z = 6.14 | significant |

| | Normalized to: 12,000 psi | | | Average | |
|---|---|---|---|---|---|
| Propellant & Temperature | Action Time | Std Dev (1) | AT+3SD | Peak Press | Velocity |
| WC846 +155 | 349 µs | 52 µs | 505 µs | 52,086 psi | 2,673 m/s |
| WC846 +70F | 381 µs | 48 µs | 525 µs | 53,378 psi | 2,726 m/s |
| WC846 -65F | 449 µs | 53 µs | 608 µs | 47,127 psi | 2,579 m/s |
| WC846FS +155 | 295 µs | 29 µs | 381 µs | 54,523 psi | 2,726 m/s |
| WC846FS +70F | 297 µs | 31 µs | 391 µs | 54,423 psi | 2,753 m/s |
| WC846FS -65F | 365 µs | 45 µs | 500 µs | 47,697 psi | 2,601 m/s |

| Difference between means: | z-score | Assessment |
|---|---|---|
| WC846 & WC846FS +155 | z = 5.50 | significant |
| WC846 & WC846FS +70 | z = 12.48 | significant |

Table 8
Propellant qualification test plan

| Test/Weapon | # Weapons Each Type | EPVAT Bbl (1) | WEAPONS M60 | M240 | M14 | M24 |
|---|---|---|---|---|---|---|
| **Dispersion** | 3 | 90 | 150 | 150 | | |
| | | | | | | |
| **Pressure/Velocity/Action Time** | | 150 | | | | |
| | | | | | | |
| **Function/Casualty/Reliability** | | | 15,000 | 45,000 | 3,000 | 1,440 |
| | | | | | | |
| **Smoke/Flash** | 1 | | 300 | 300 | | |
| | | | | | | |
| **Environmentals** | | | | | | |
| High Temp. Function | 3 | | 6,000 | 6,000 | | |
| Low Temp. Function | 3 | | 6,000 | 6,000 | | |
| Temp/Humidity | 1 | | 200 | 200 | | |
| Thermal Shock | 1 | | 200 | 200 | | |
| 28 Day Hot Storage | 1 | | 250 | 250 | | |
| 28 Day Cold Storage | 1 | | 250 | 250 | | |
| | | | | | | |
| **Cookoff** | 1 | | 4,000 | 4,000 | | |
| | | | | | | |
| **Time of Flight** | | 90 | | | | |
| | | | | | | |
| **Toxic Fumes** | 1 | | 1,000 | 1,000 | | |
| | | | | | | |
| **Noise** | 1 | | 5 | 5 | | |
| | | | | | | |
| **Barrel Performance (3)** | 3 | | | 5,000 | | |
| | | | | | | |

**Requirements**

Total Rounds Required: 106,480
Total Rounds Requested: 113,000
M240, M60 Machine Guns: 6 each
M24, M14 rifles: 3 each

(1) Only one test barrel is used in each test.
(2) M60 barrels are Stellite lined, and have better wear characteristics than the M240
(3) Conducted in 700 rd sustained fire.

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